The evolution of disks around intermediate-mass young stars

as seen with MIDI

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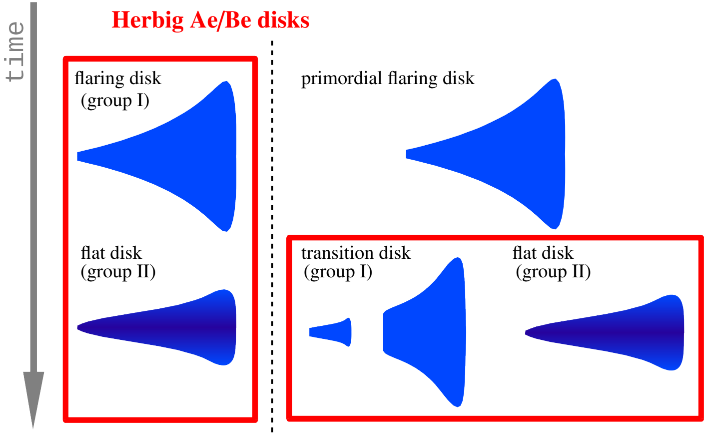
Intro: evolution scenarios for Herbig Ae/Be disks



Meeus et al. (2001)
SED

Maaskant et al. (2013)
SED + mid-IR imaging

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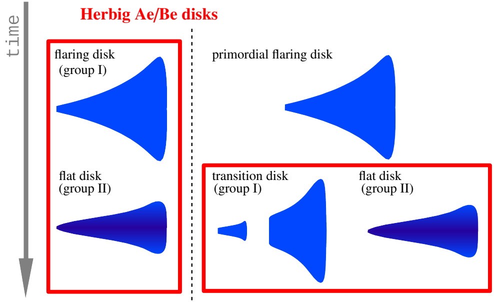

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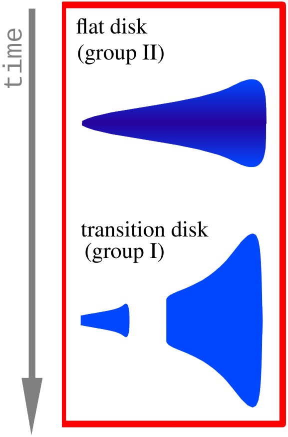
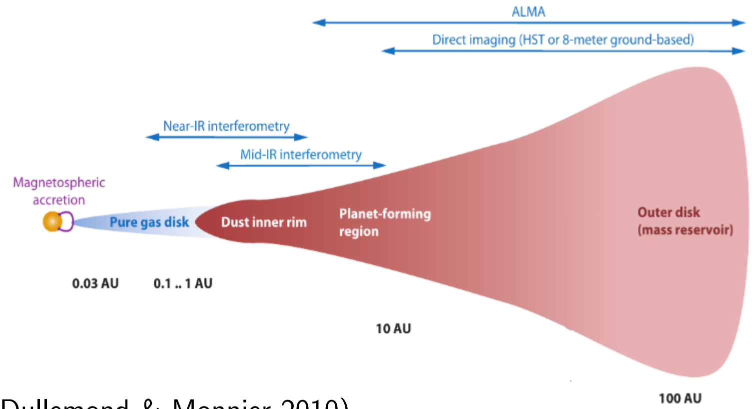


A different/new evolution scenario?

Mid-infrared interferometry



(Dullemond & Monnier 2010)

VLTI/MIDI observations

T Tauri: LkHα 330, LkCa 15, DR Tau, GM Aur, SU Aur, CR Cha, DI Cha, HP Cha, FM Cha, WW Cha, CV Cha, T Cha, HD 142560, HD 143006, Elias 2-24, Elias 2-28, V2129 Oph, V2062 Oph

Herbig Ae: V892 Tau, RY Tau, AB Aur, HD 31648, UX Ori, HD 36112, HD 36917, CQ Tau, V1247 Ori, HD 38120, HD 259431, HD 50138, HD 72106, HD 95881, HD 97048, HD 98922, HD 100453, HD 100546, HD 104237, HD 135344 B, HD 139614, HD 142666, HD 142527, HD 144432, HD 144668, Elias 2-30, HD 150193, AK Sco, KK Oph, 51 Oph, HD 163296, HD 169142, R CrA, T CrA, HD 179218

Herbig Be: HD 45677, R Mon, HD 87643, MWC 297, MWC 300

Massive: MWC 349

Embedded: VY Mon, DK Cha, HBC 639

Debris/weak disk: β Pic, HD 109085, V2246 Oph

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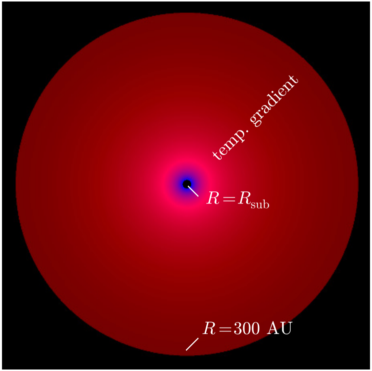
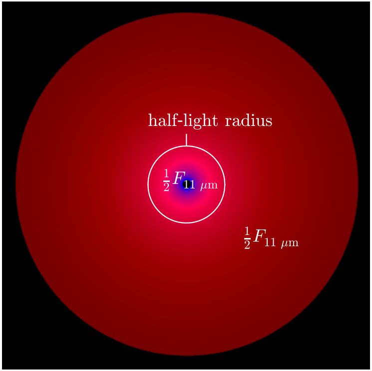
65 objects, 5 archive observations/target (on average)

Modeling

Temperature-gradient model (2 free parameters):

$$I_\nu(R) = A\, B_\nu\big(T(R)\big), \quad \text{where} \quad T(R) = T_{\text{sub}} \left(\frac{R}{R_{\text{sub}}}\right)^{-q}$$





Size-luminosity diagram

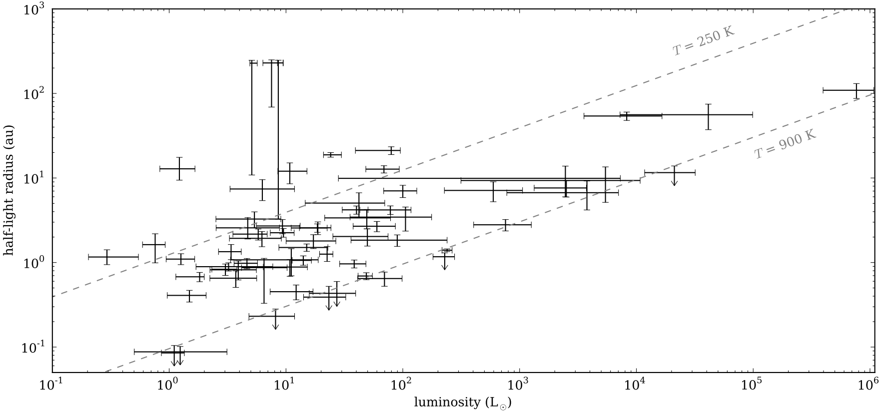


Fig MIDI size-luminosity diagram for protoplanetary disks

Size-luminosity diagram

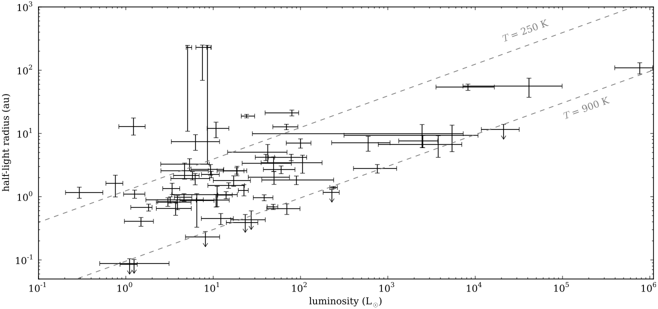


Fig MIDI size-luminosity diagram for protoplanetary disks

Results:

1. in general, disks around more luminous sources appear bigger
2. disks around similar sources can be very different
   $\Rightarrow$ intrinsic diversity?
   $\Rightarrow$ evolutionary stages?

Size-color diagram (Herbig Ae stars)

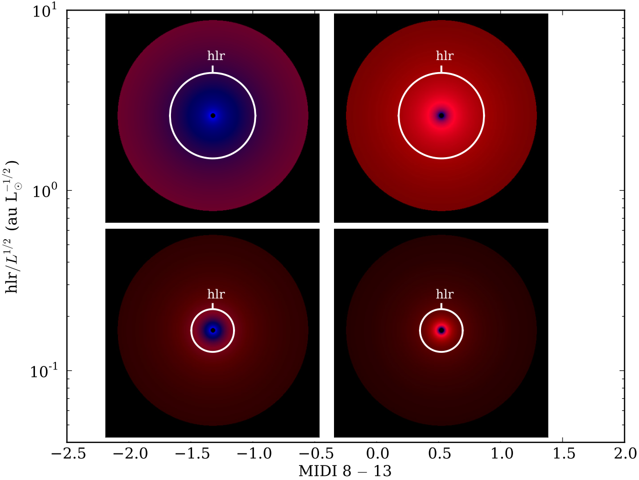


Fig Half-light radius (hlr) vs. MIDI 8 μm − 13 μm color

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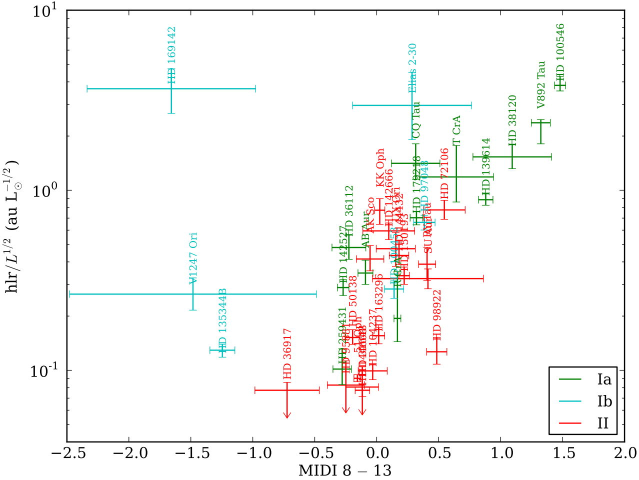

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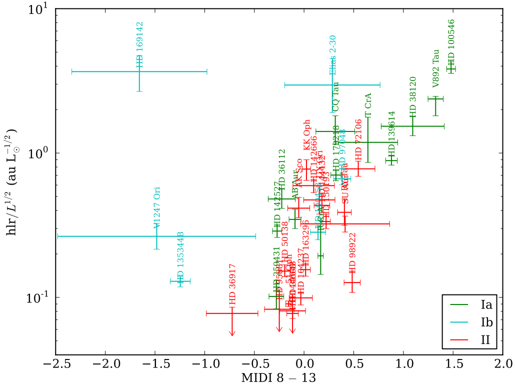

Fig Half-light radius (hlr) vs. MIDI 8 μm − 13 μm color

Results:

1. large sources are redder, small sources bluer
2. *overlap* between Type Ia and Type II sources

Model size-color diagram

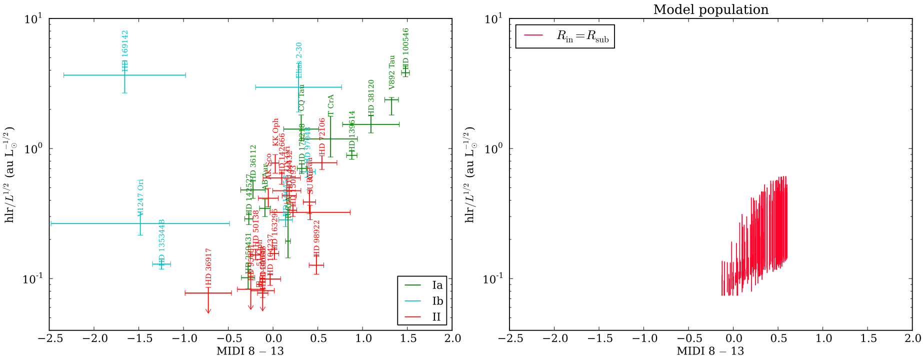

Fig Half-light radius (hlr) vs. MIDI 8 μm − 13 μm color for model population without varying $R_{\rm in}$

Model size-color diagram

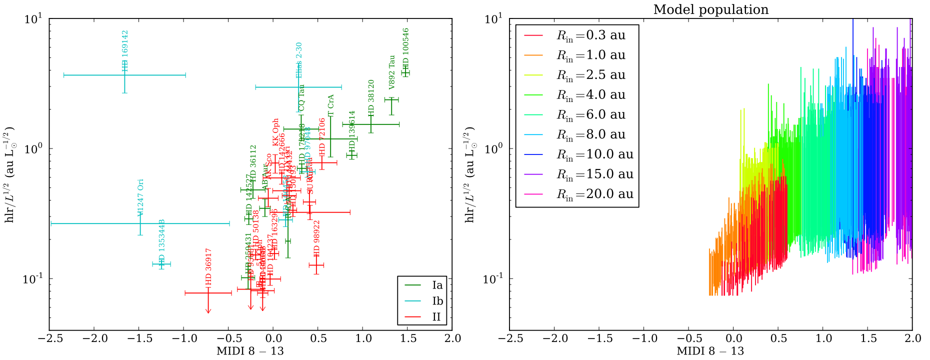

Fig Half-light radius (hlr) vs. MIDI 8 μm − 13 μm color for model population with varying $R_{\rm in}$

Model size-color diagram

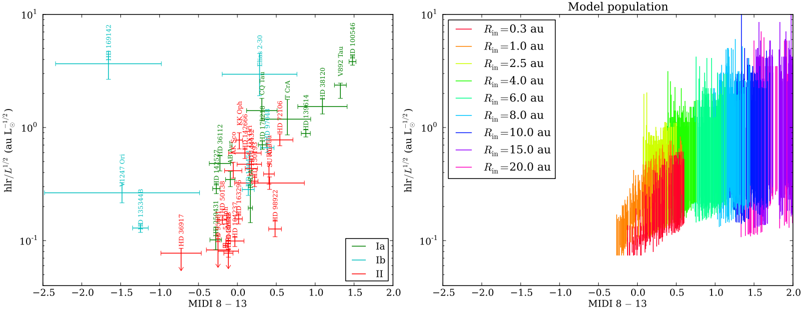

Fig Half-light radius (hlr) vs. MIDI 8 μm − 13 μm color for model population with varying R_{in}

Results:

1. no fundamental discrepancy between type I and II sources
2. clear hints that some type II sources have gap
   (e.g., Schegerer et al. 2013, Chen et al. 2012)

⇒ strict separation between I and II unjustified?

A new evolution scenario for Herbig Ae disks?

Possible scenario

Herbig stars start with "full" flat disks (II without gap)

$\Downarrow$ large-body formation (slow)

Disk with forming gap (II with gap or I)

$\Downarrow$ planet(?)-disk interaction, grain collisions

Disk with large gap, flaring outer disk (I)

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Other observations/simulations:

- time scales for grain growth: $< 1\,\mathrm{mm}$ fast, $> 1\,\mathrm{mm}$ slow (Windmark et al. 2012)
- crystallinity in wall type I: shocks due to planet formation (Mulders et al. 2011)
- PAH features not in agreement with I$\rightarrow$II (Dullemond et al. 2007)
- grain growth in disks: small-grain population reappears (Windmark et al. 2012)
- no contradiction with correlation grain size vs. flaring (Juhasz et al. 2010)

Conclusions

MIDI: inner-disk structure of protoplanetary disks

Herbig Ae/Be disks: **I** = transition, **II** = flat

MIDI + Herbig Ae/Be disks: **I** and **II** overlap, some **II**s with gap?

Evolution scenario: flat disks → transition disks?